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JAMMING SIGNAL REDUCTION IN SPREAD SPECTRUM SYSTEMS.(U)
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Abstract

A phase-locked loop based narrowband jamming signal cancellation system was built and tested to experimentally determine the degree of cancellation achievable. A reduction of 28.5 db was obtained for CW jamming signals. This is considered to be an upper limit. A reduction of 11.5 db was obtained for an amplitude modulated jamming signal. It is felt that this can be increased to 15 - 20 db with additional envelope phase control circuitry.

System Description

For a spread spectrum (SS) system operating in a CW jamming environment the composite received signal is

$$r_1(t) = S_{ss}(t) + A_j \cos(\omega_j t + \theta)$$

where $S_{ss}(t)$ is the SS signal with power S_R, center frequency f_c and bandwidth W_{ss}, and $A_j \cos(\omega_j t + \theta_j)$ is the jamming signal with power

$$J_R = \frac{A_j^2}{2}$$

For the case of high jamming-to-signal ratio (JSR) the composite received signal consists of a relatively large-power jamming signal concentrated at a single frequency plus a relatively small-power SS signal spread over a large frequency range. A narrowband tracking circuit, tracking the jamming signal, can therefore provide an accurate reproduction of the jamming signal, and this signal can be used to cancel the jamming signal prior to the SS correlation processing in the receiver. The proposed system is illustrated in Figure 1. With perfect frequency tracking, the result, as shown in [1], is a reduced CW jamming signal with amplitude

$$A_{jc} = \sqrt{A_j^2 + \hat{A}_j^2 - 2A_j\hat{A}_j \cos(\theta_j - \hat{\theta}_j)}$$

This expression provides the relationship between amplitude and phase estimation accuracies and cancellation effectiveness. From this relationship the CW jamming signal power after cancellation is shown to be

$$J_c = \overline{(\theta_j - \hat{\theta}_j)^2}\; J_R + \frac{1}{2}\overline{(A_j - \hat{A}_j)^2} \qquad (1)$$

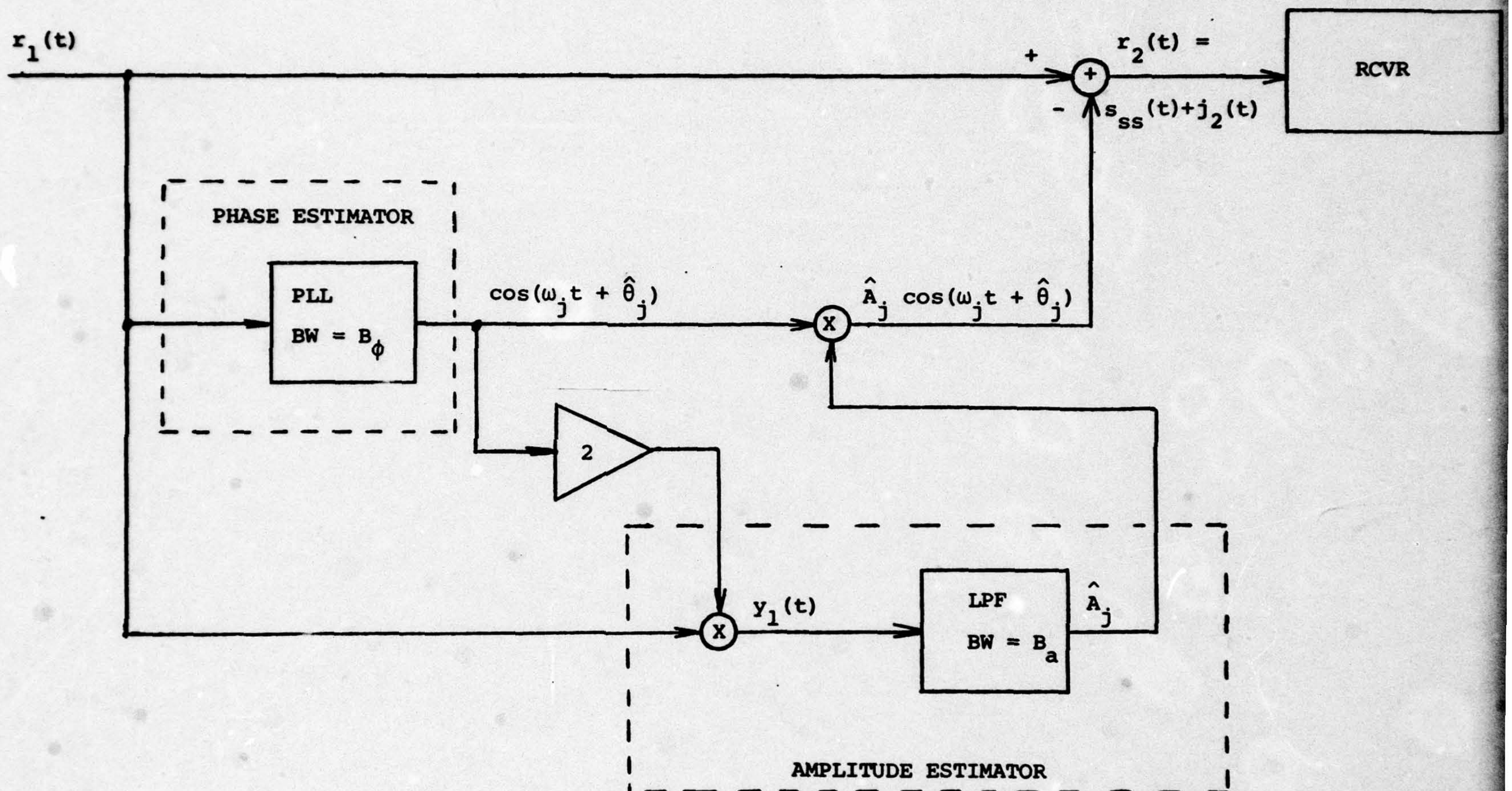

Figure 1. System Block Diagram

under operating conditions of interest. With idealized phase and amplitude estimation techniques this becomes

$$J_c = \frac{B_\phi + B_a}{W_{ss}} S_R \tag{2}$$

where

B_ϕ = Bandwidth of the Phase Estimator

B_a = Bandwidth of the Amplitude Estimator

W_{ss} = SS Signal Bandwidth

S_R = SS Signal Power

The effective JSR after cancellation is

$$\frac{J_c}{S_R} = \frac{B_\phi + B_a}{W_{ss}} \tag{3}$$

If the tracking circuit bandwidths B_ϕ and B_a are orders of magnitude smaller than the SS signal bandwidth W_{ss}, the effective JSR is orders of magnitude less than one, and is, in fact, independent of the received jamming signal and SS signal powers.

Cancellation effectiveness can be expressed in terms of rms phase and amplitude estimate errors by rewriting (1) as

$$\begin{aligned} J_c &= \overline{(\theta_j - \hat{\theta}_j)^2}\ J_R + \frac{1}{2} A_j^2\ \frac{\overline{(A_j - \hat{A}_j)^2}}{A_j^2} \\ &= \overline{\phi_e^2}\ J_R + J_R\ \overline{A_e^2} \\ &= (\overline{\phi_e^2} + \overline{A_e^2})\ J_R \end{aligned} \tag{4}$$

where

$\overline{\phi_e^2}$ = mean-square phase estimation error

$\overline{A_e^2}$ = normalized mean-square amplitude estimation error

Reduction in jamming signal power is therefore simply expressed as

$$\frac{J_c}{J_R} = \overline{\phi_e^2} + \overline{A_e^2} \tag{5}$$

This expression indicates that rms phase estimation error of 0.1 rad and rms amplitude estimation error of 10% would produce a 17 db reduction in JSR, figures which appear to be realistic. The objective of the research program was to experimentally determine the degree of reduction possible, for both CW and other narrowband jamming signals.

System Implementation

The block diagram of the system as implemented is shown in Figure 2. The system operates at a center frequency of 1 MHz, a frequency which is high enough to exhibit the practical problems of phase control and low enough to permit IC implementation. All major components of the system were initially designed and built with ICs. However a Wavetek Phaselock Generator was used in place of the IC PLL for the performance measurements because of its greater flexibility in matching signal levels, and its sinusoidal output signal as opposed to the squarewave output of the PLL.

The Phaselock Generator locks onto and tracks the jamming signal over a frequency range of 1 $\pm$ 0.2 MHz. Its output is a constant peak amplitude sinusoidal signal which is used as the local oscillator signal for both the Synchronous Demodulation and Balanced Modulator.

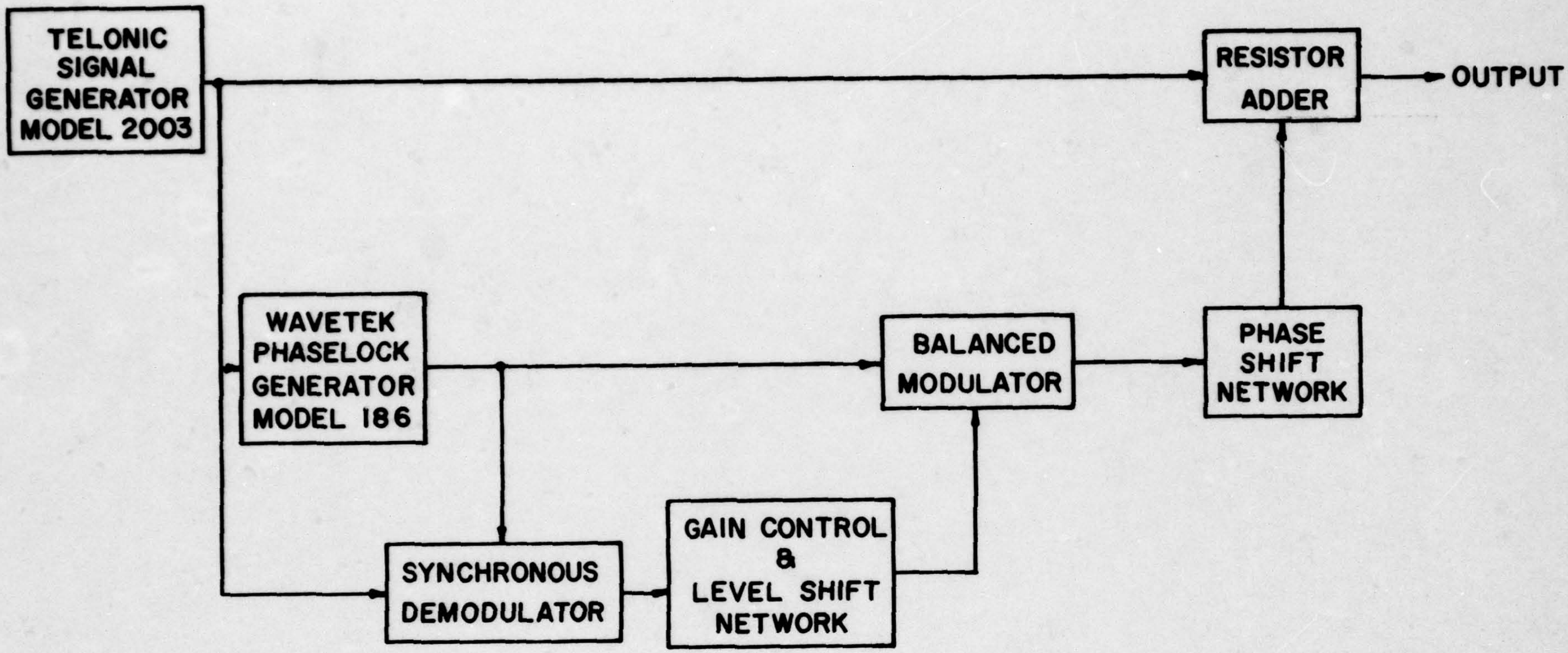

Figure 2. SYSTEM BLOCK DIAGRAM AS IMPLEMENTED

The MC 1496 P IC Synchronous Demodulator provides differential output signal consisting of the demodulated jamming signal amplitude plus a double frequency term. The double frequency term is eliminated by the R - C low pass filter. The remaining signal is the estimate of the jamming signal amplitude.

Two op amp ICs are used to convert the differential signal to a single-ended signal, and to provide DC level shifting and gain adjustment. Of course the gain between the demodulator and modulator, and the DC level into the modulator are critical factors in the cancellation effectiveness and dynamic range characteristics of the system. The existing design has as interaction between gain and DC level which makes adjustment tedious and severely limits dynamic range. This is considered to be the weakest link in the present system, but one which can be overcome by the addition of a feedback circuit to drive the gain and DC level so as to accomplish a "nulling" of the canceled signal.

Another critical factor in this section of the system, i.e. between demodulator and modulator, is phase shift. The signal here is the peak amplitude or envelope of the jamming signal. If the jamming signal is amplitude modulated, any phase shift of this signal will result in a reproduced jamming signal whose envelope is not exactly in phase with the envelope of the original jamming signal. Poor cancellation will result even though the carrier phases are identical.

The Balanced Modulator uses the amplitude estimate from the op-amp circuit as the modulating signal and the phase-locked signal from the PLL as the carrier to create an estimate of the jamming signal. In order to cancel the original jamming signal with this estimate, the two carriers must be 180^{o} out of phase and the signals added. Of the total 180^{o} phase shift, part comes about from phase shift in the circuitry and the remainder

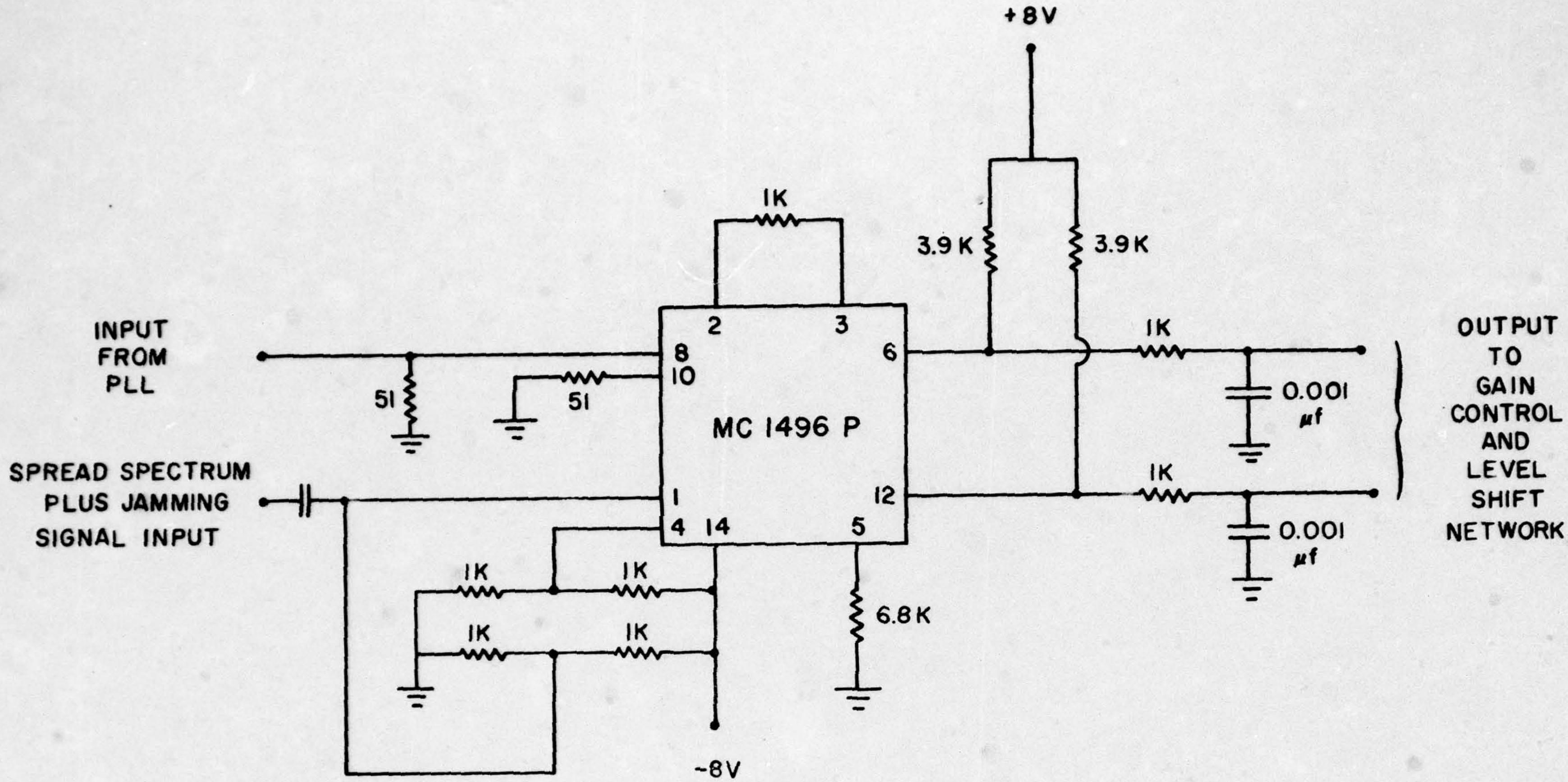

Figure 3. SYNCHRONOUS DEMODULATOR

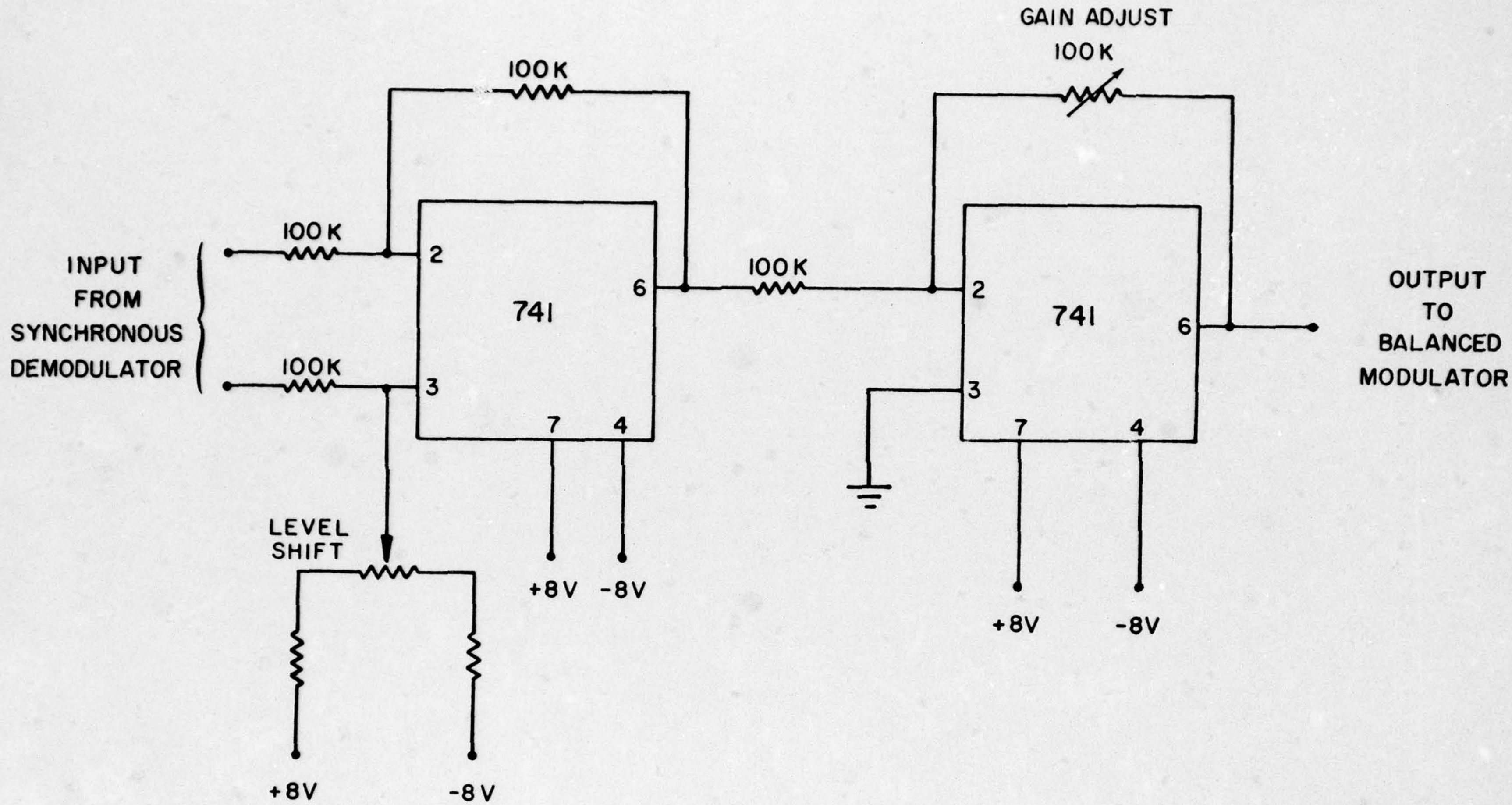

Figure 4. GAIN CONTROL AND LEVEL SHIFT NETWORK

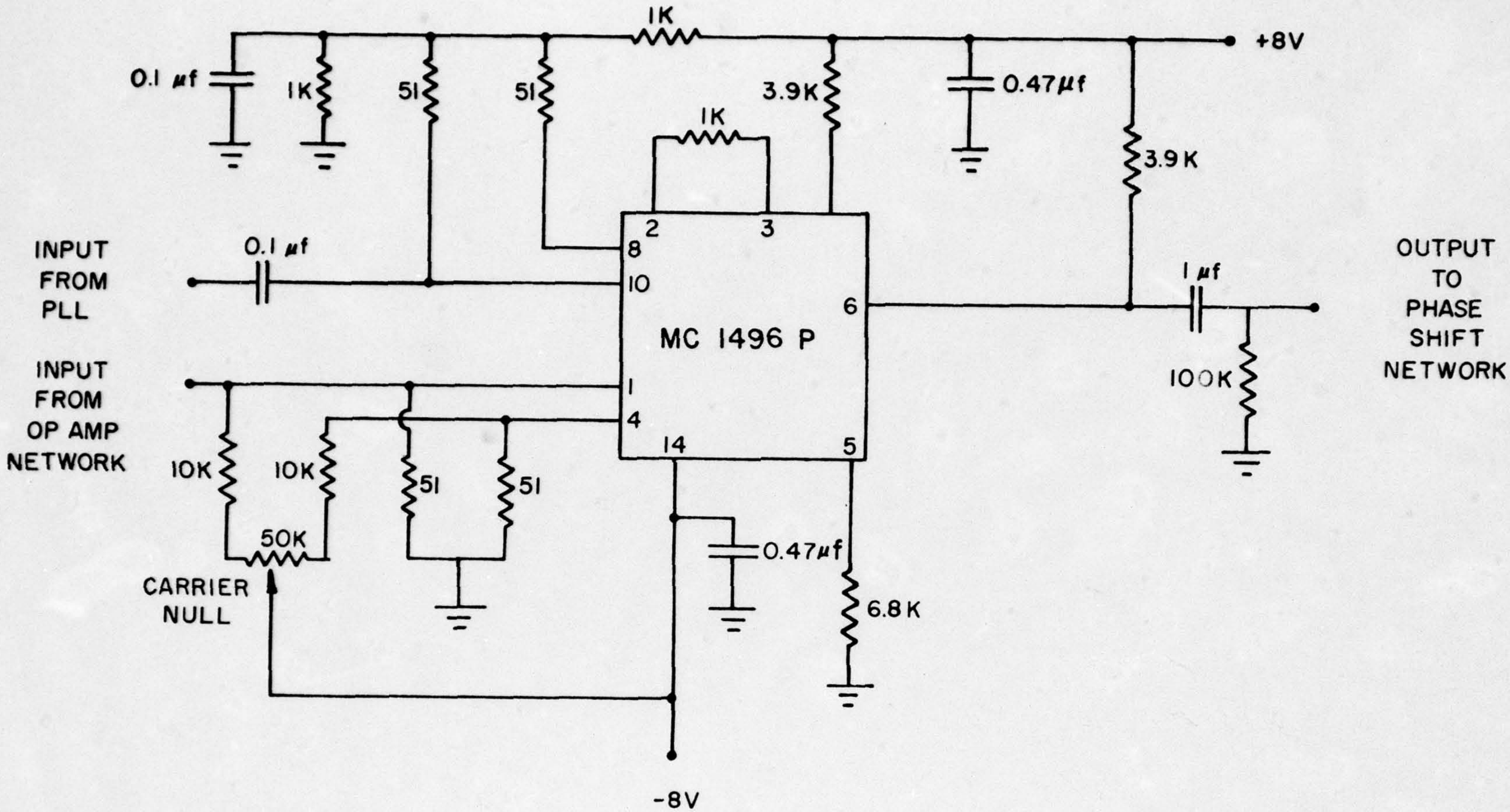

Figure 5. BALANCED MODULATOR

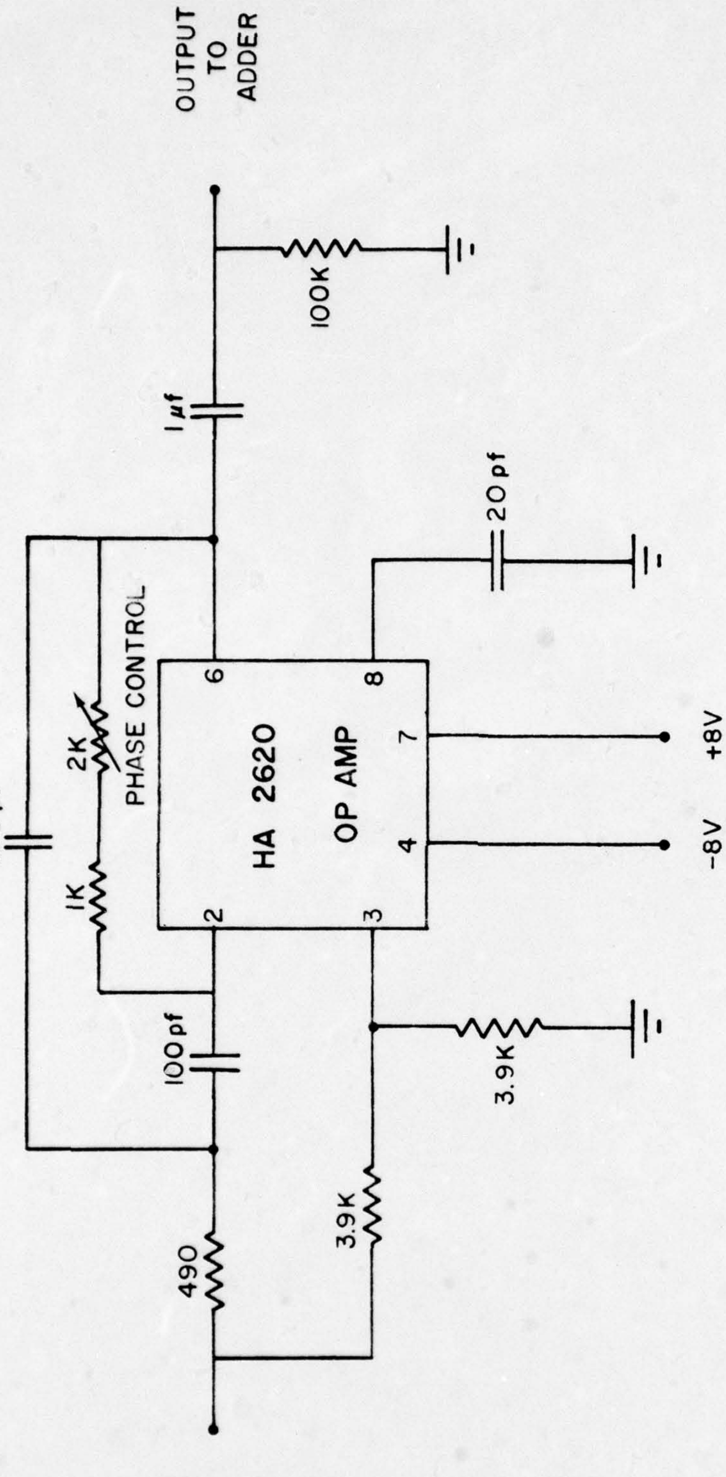

Figure 6. PHASE SHIFT NETWORK

is introduced by the Phase Shift Network. This active filter phase shift circuit introduces an adjustable amount of phase shift at a single frequency. The phase shift is somewhat frequency dependent so that the resulting group delay of this circuit degrades the cancellation effectiveness of the system for amplitude modulated jamming signals. The group delay effect can be minimized by the addition of an appropriate equalizer netowrk.

The original signal and the estimate of the jamming signal are matched and added by a resistor divider/adder circuit to achieve the cancellation.

Experimental Results

The 1.2 volt peak-to-peak CW jamming signal shown in Figure 7 was reduced to the 0.045 volt peak-to-peak signal of Figure 8. This is a signal reduction of 28.5 db. This was accomplished through manual adjustment of gain and phase shift, and the residual signal is primarily a consequence of imperfections in the basic sinusoidal wave shapes. Thus the 28.5 db figure is an upper limit on the reduction possible using the standard IC components employed here.

Figure 9 shows a jamming signal which is amplitude modulated with a 1 KHz tone at a modulation index of 0.25. Figure 10 shows the match between the input and output of the Synchronous Demodulator. Although the match appears to be perfect, there is some slight phase mismatch which effects cancellation effectiveness. Figure 11 is the residual left after cancellation, indicating a reduction of 11.5 db. As noted earlier, the effectiveness suffers because the envelopes of the two signals are not in phase, rather than from a mismatch in carrier phases. This can be reduced by the incorporation of an equalizer network to compensate for the group delay of the system.

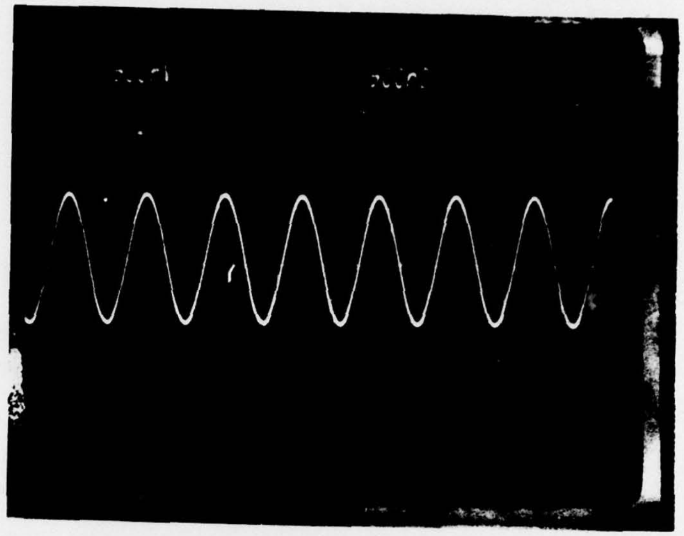

Fig. 7 CW Jamming Signal

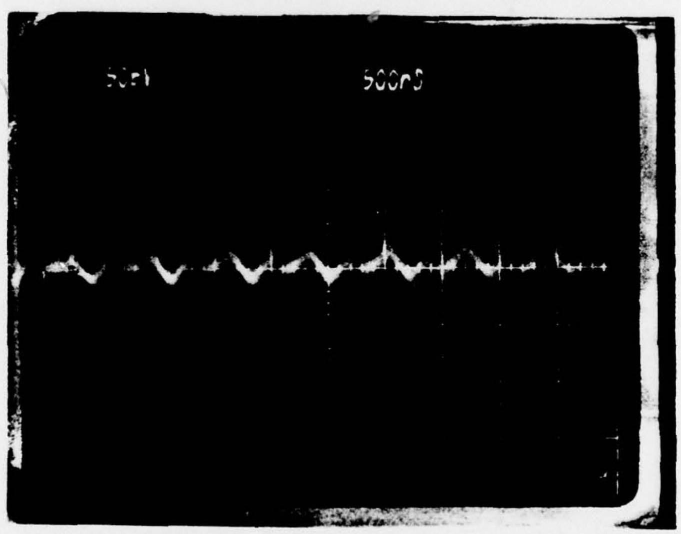

Fig. 8 Residual of CW Jamming Signal

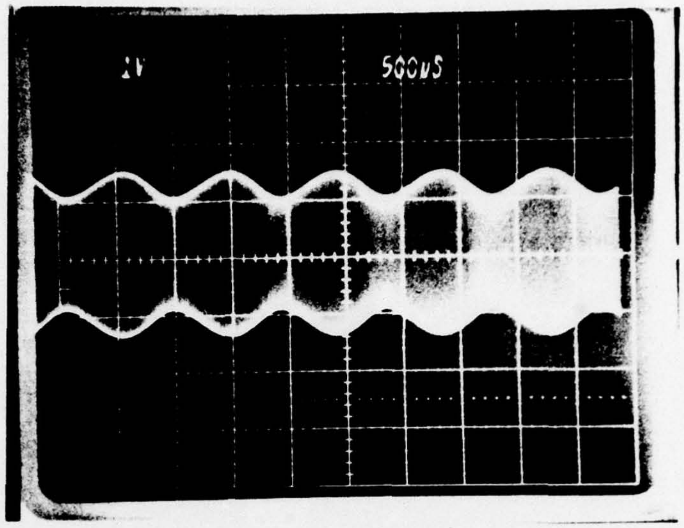

Fig. 9 AM Jamming Signal

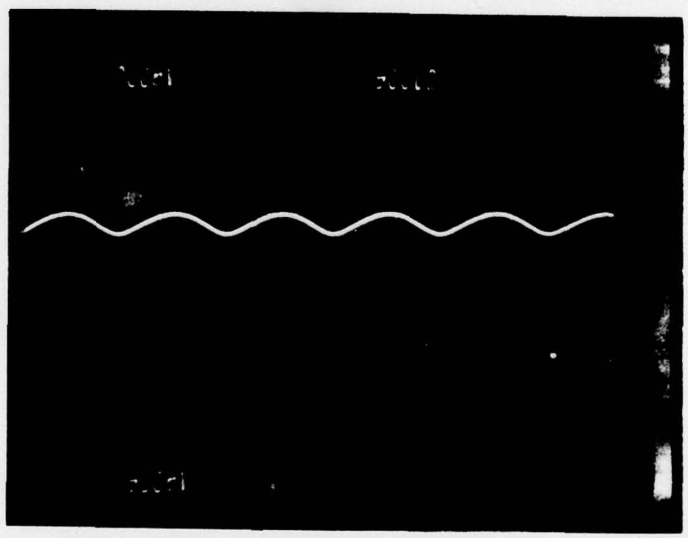

Fig. 10 Input and Output (Highlighted)
of Synchronous Demodulator

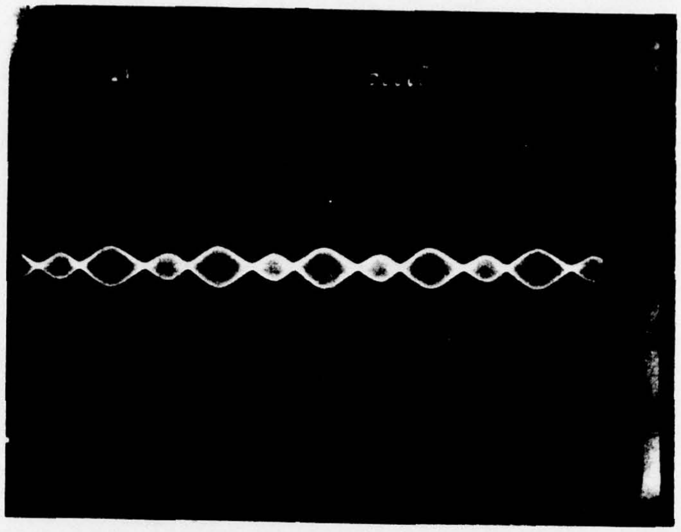

Fig. 11 Residual of AM Jamming Signal

Conclusions

The 28.5 db reduction in the CW jamming signal should be considered a practical upper bound, with nominal performance on the order of 20 db achievable in working systems. Dynamic range can be improved by the incorporation of a null detector-type feedback circuit to drive the amplitude estimate signal so as to minimize the cancellation residual.

The comparatively low 11.5 db reduction of the AM jamming signal is due to the phase difference between the envelopes of the original signal and the jamming signal. This phase difference can be reduced by better phase control in the baseband portion of the system and the addition of an equalizer network to offset group delay in the RF sections. It is felt that a reduction of 15 - 20 db should be achievable.

The PLL approach appears to be the most promising of those proposed to date. New devices, such as the frequency - selective limiter, give some promise of significant improvement of jam resistance to narrowband signals.

Related Work

A PPL CW interference cancellation system, similar to the one reported herein, was granted U.S. Patent No. 4,027,264 on 31 May 1977 [2]. In that system the CW interference is assumed to be added to the information signal prior to modulation in the transmitter. The tracking loop is therefore placed after the demodulator in the receiver so that it is a baseband loop rather than a RF loop. The tracking, estimation and cancellation techniques employed in the two systems are basically the same. No implementation of that system is specified in the patent. The critical component in that system is the "Null Detector" feedback circuit which adjusts the amplitude of the reconstructed interfering signal for maximum cancellation.

A system in which a hardlimiter, rather than a PLL, is used to generate the phaselocked signal has been proposed and investigated by Lewis [3]. The amplitude estimate is obtained by the same Synchronous Demodulator - Low Pass Filter technique used here. The use of a limiter eliminates loop acquisition and tracking problems. The major disadvantage is that multiple jamming signals cannot be handled.

An exotic device for frequency - selective limiting of narrowband interfering signals was reported by Jackson and Orth [4] in 1967. The device, based on nuclear magnetic resonance, produces independent limiting of multiple, narrowband signals to a predetermined threshold level. The experimental model tested in 1966 exhibited a 30 db improvement in signal-to-interference ratio. However the limited bandwidth (1.2 KHz at 30 MHz) and high insertion loss (47 db) would limit its utilization.

References

[1] Bouvier, M. J., Jr., "The Rejection of Large CW Interferers in Spread Spectrum Systems," *IEEE Trans. on Comm.*, Vol. COM-26, No. 2, Feb. 1978, pp. 254-6.

[2] Gutleber, F. S., *Phase Lock Loop Multitone Interference Canceling System*, U.S. Patent 4,027,264, Issued 31 May 1977.

[3] Lewis, J. L., "Bit Error Probability of a Large Jammer Cancellation System," *Conference Record*, Vol. 3, pp. 35.3.1 - 35.3.5, National Telecommunications Conference, Dec. 1978.

[4] Jackson, D. R. and R. W. Orth, "A Frequency - Selective Limiter Using Nuclear Magnetic Resonance," *Proc. IEEE*, Vol. 55, No. 1, Jan. 1967, pp. 36-45.

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